NIKE3D Code Support and Enhancement

The objective of this work is to support, maintain, and enhance the implicit structural mechanics finite-element code NIKE3D. The code is used by engineering analysts to evaluate static and low-frequency dynamic response. User support includes assisting analysts in model debugging and general analysis recommendations. Maintenance includes bug fixes and code porting to the various platforms available. New features are added to accommodate engineering analysis needs.

Project Goals

Our goals included implementing the following enhancements:

1. An advanced contact algorithm, known as a mortar method. This involved modifications to existing prototype code, eliminated any fixed-memory constraints, and extended data structures to accommodate multiple surface definitions. In addition, an improved algorithm was implemented for computing and integrating the overlapping segments.
2. User-requested thermal expansion capabilities were added to NIKE3D material models 1 (hypoelastic), 15 (hyperelastic), and 27 (hyperelastic-plastic material).
3. Interface to parallel (threaded) symmetric and unsymmetric linear equation solvers for the Linux and AIX platforms. We also ported NIKE3D to the Red Hat Linux and AIX operating systems.

Relevance to LLNL Mission

Structural analysis is one of the most important functions of LLNL's mechanical engineering efforts, supporting assessment activities. The in-house codes are crucial for meeting these needs. NIKE3D, in particular, is a premier code for handling difficult nonlinear static structural analysis problems.

FY2005 Accomplishments and Results

A new mortar contact method has demonstrated vastly superior nonlinear convergence behavior and has led to a number of papers. This approach effectively smoothes the numerical behavior near the interface and eliminates instabilities ("locking") long observed with standard contact methods. Consequently, contact analyses that failed in the past can now be successfully analyzed using implicit finite elements (Fig. 1).

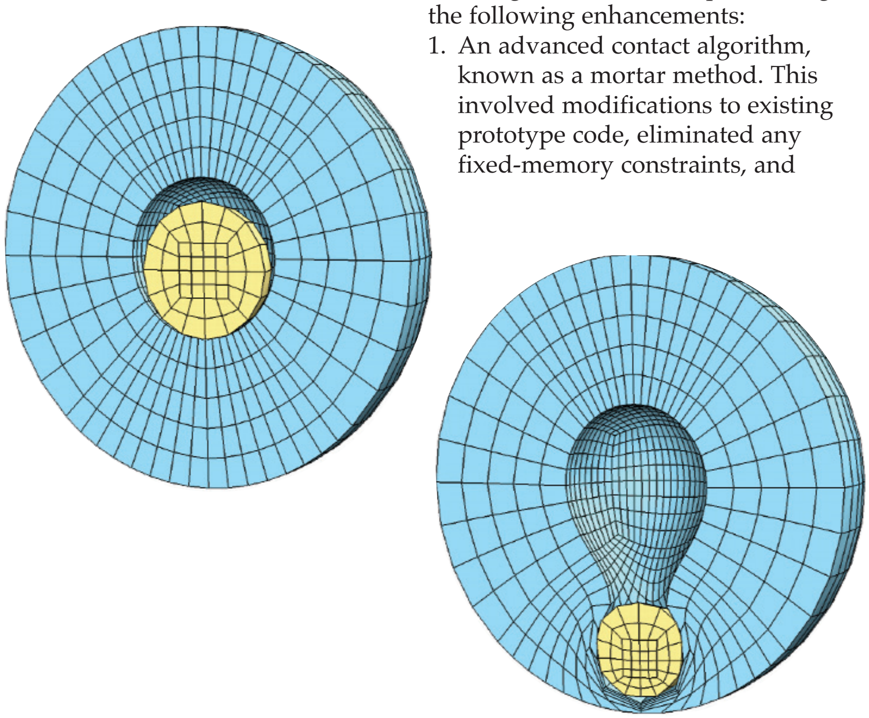

Figure 1. Elastic sphere forced into thick elastic shell. Analysis was performed with implicit finite-element method using mortar contact. Standard contact methods cannot nearly approach this significant amount of deformation with implicit finite elements.

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On the other hand, the programmed data structures involved with mortar contact proved much more complicated than the standard, widely-used node-on-segment algorithms in most codes. Consequently, while the prototype code established the feasibility of the method, many simplifying assumptions limited its applicability to large-scale simulation. In the present work, upgraded data structures were implemented that provide the ability for multiple contact surface definitions. Figure 2 demonstrates the compression of four blocks where three individual contact surface definitions were used. The results in Fig. 3 show the applied force vs. time from analyses using the mortar contact and the default node-on-segment algorithm. For a variety of reasons, the standard contact algorithm fails when the soft blocks experience strains around 8%, whereas the mortar contact algorithm can go past 50% strains. This capability is now being used for production work by engineering analysts, showing better numerical behavior and simplifying their model generation efforts.

Related References

1. Puso, M. A., and T. A. Laursen, "A Mortar Segment-to-Segment Contact Method for Large Deformation Solid Mechanics," *Computer Methods in Applied Mechanics and Engineering*, **193**, pp. 601-629, 2004.
2. Puso, M. A., and T. A. Laursen, "A Mortar Segment-To-Segment Frictional Contact Method for Large Deformations," *Computer Methods in Applied Mechanics and Engineering*, **193**, pp. 4891-4913, 2004.

FY2006 Proposed Work

In addition to the ongoing general technical support for NIKE3D users, the following enhancements are currently planned:

1. Node relocation during initialization for curved, unmatched mortar contact surfaces that have unintentional interpenetrations defined by the original mesh geometry.
2. Improved quasi-Newton nonlinear equation solvers to handle the evolving active contact constraints. Algorithms that perform secant updates such as BFGS but better account for active constraints will be targeted.

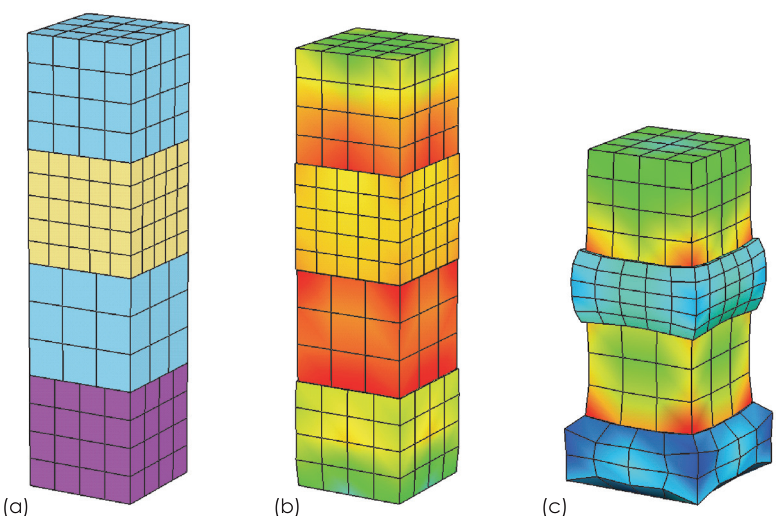

Figure 2. (a) Undeformed soft and hard blocks separated by three individually defined contact surfaces. A vertical load is applied to the top block. (b) Effective stress at the maximum deformation attainable using the standard contact in NIKE3D. The soft blocks experience about 8% strain. (c) NIKE3D mortar contact results after 50% strain to soft blocks.

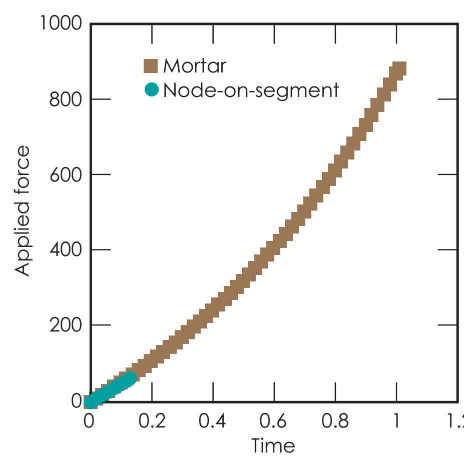

Figure 3. Applied force vs. time for vertically loaded blocks from analyses using mortar and node-on-segment contact algorithms. The plot displays the enhanced robustness of the mortar method.